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Flight Evaluation of a Spoiler Roll Control System on a Light Twin-Engine Airplane

David L. Kohlman

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Prepared for
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National Aeronautics
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1. Introduction

Spoilers are widely used for primary or supplementary roll control on large, multi-engine jet aircraft. They are invariably actuated by irreversible powered control systems. Thus, any nonlinearities in hinge moments or rolling moments can be disguised from the pilot by properly tailoring the system.

Unfortunately, there has been until recently a dearth of spoiler design information in the open literature which would be useful to the light airplane designer. Only one general aviation airplane, the high performance, twin turboprop Mitsubishi MU-2, employs spoilers for roll control on the production version.

There are several reasons for using spoilers rather than ailerons for roll control:

1. Spoilers permit the use of full span trailing edge flaps. This permits higher wing loading and corresponding improvements in cruise performance and ride quality.
2. Spoilers can be designed to eliminate adverse yaw.
3. Spoilers can be designed in conjunction with flap systems such that roll power remains high at approach speeds, rather than becomes sluggish as with ailerons.
4. Spoilers, once installed, can be incorporated into a flight path control system which offers easier and more accurate control during final approach.

The Robertson Aircraft Corporation recently developed a spoiler system for installation on the Piper Seneca. The purpose of this report is to present the results of a flight test program to determine

the characteristics of this spoiler system. These data, when added to the growing body of data on other spoiler systems developed for general aviation aircraft application (Refs. 1 - 9), should be helpful to the designer who wishes to incorporate spoilers in a light aircraft configuration.

2. Nomenclature

b	wing span, meters (feet)
c	wing chord, meters (feet)
C_L	lift coefficient
C_ℓ	rolling moment coefficient
$C_{n_{\delta S}}$	yawing moment derivative
F_W	control wheel force, newtons (lbf)
h	height of spoiler trailing edge above wing. meters (feet)
p	roll rate
V	true airspeed, knots (ft per sec.)
V_C	calibrated airspeed, knots
W	gross weight, newtons (lbf)
β	sideslip angle
δ_S	spoiler deflection angle
δ_W	wheel deflection angle
θ	pitch angle
ϕ	roll angle

3. Configuration Description

A modified Piper PA34-200 Seneca, a twin-engine, six-place airplane, was the test vehicle. The modifications were as follows:

1. The normal ailerons were removed.
2. The trailing edge flaps were extended outboard so that they became essentially full span flaps.
3. The flaps were mounted on tracks instead of the standard plain hinges.
4. The tip of the flap slot was moved aft 2.0 inches (3.17% C) to accommodate the increased Fowler action of the flaps. The flap travel path was modified to provide a greater slot width at intermediate flap positions.
5. The flap drive system was changed from a manual to an electrically powered system.
6. Plain hinged, flat plate, upper surface spoilers were installed to provide roll control. The trailing edge of each spoiler constitutes the lip of the flap slot over the portion of the span covered by the spoilers. This design is known as a slot-lip spoiler.

The slot-lip spoiler has the advantage of providing nearly linear control effectiveness with the flaps down as well as up. It has the disadvantage of not allowing spoiler down travel with flaps up, because the spoiler rests against the leading edge of the flap. This was resolved by allowing the down traveling spoiler to elastically deform with the spoiler trailing edge against the flap. This provided a firm centering force with flaps up.

With flaps down, the control linkage system changes so that both spoilers come up to a 6 degree bias deflection and the spoiler down-travel increases. This arrangement eliminated a float-up problem caused by opening the flap cavity. It also provides a high initial roll sensitivity with small deflections, resulting in excellent control characteristics.

Figure 3.1 shows a cross-section of the spoiler installation and a planview of the Seneca with the spoiler and flap modification. Figure 3.2 shows the Robertson-Seneca in the cruise configuration with spoilers down. Spoilers and flaps are fully deflected in Figure 3.3. A bottom view of the flaps with new external flap tracks is presented in Figure 3.4.

The spoilers are actuated by the conventional control wheel through a direct cable link to a bellcrank in each wing. The bellcrank contains a cam which drives a pushrod connected to the spoiler. A schematic of the system is shown in Figure 3.5.

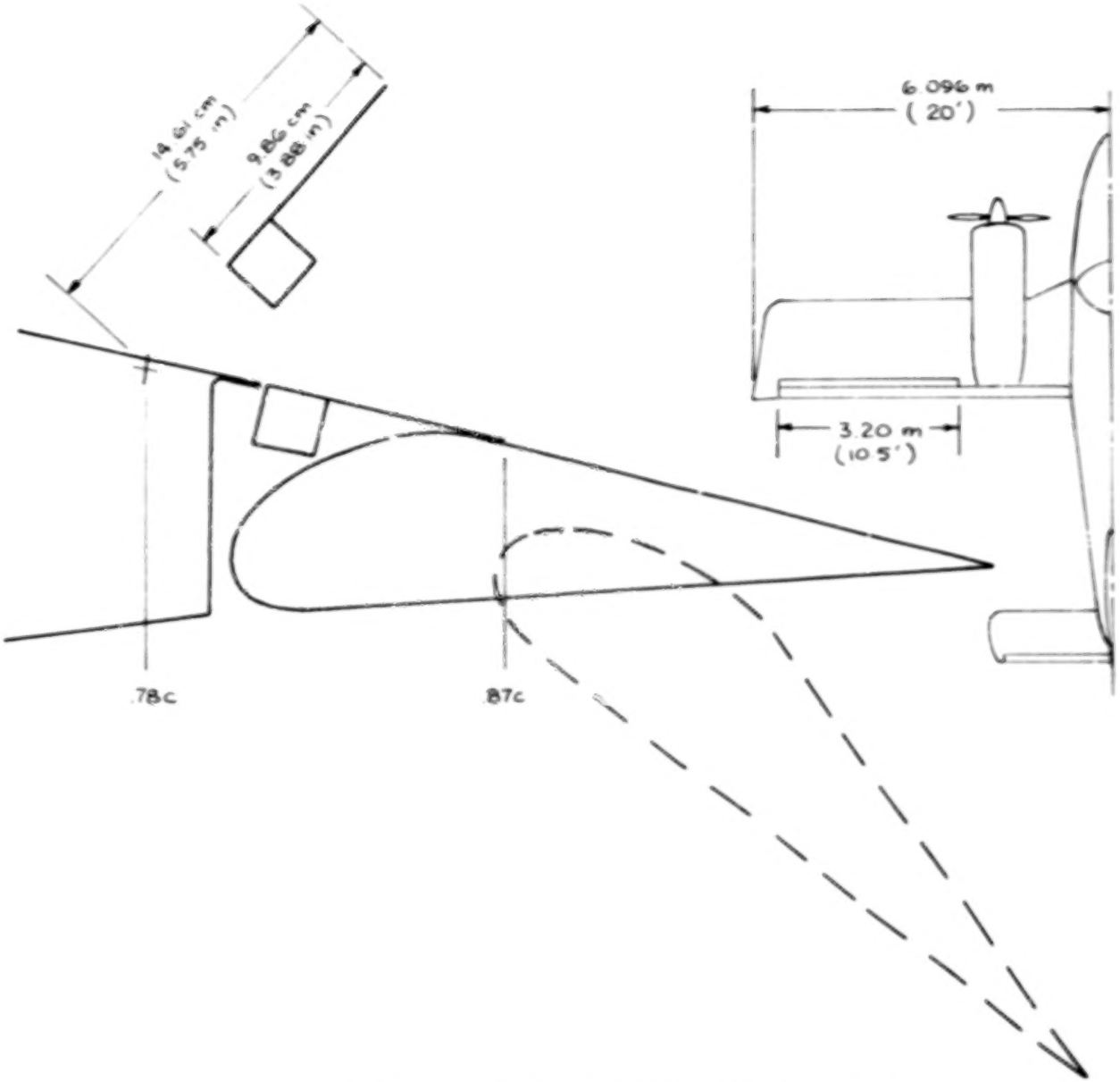


Figure 3.1. Robertson-Seneca Spoiler Installation

Figure 3.2 Cruise Configuration of the the Robertson-Seneca Flaps and Spoilers

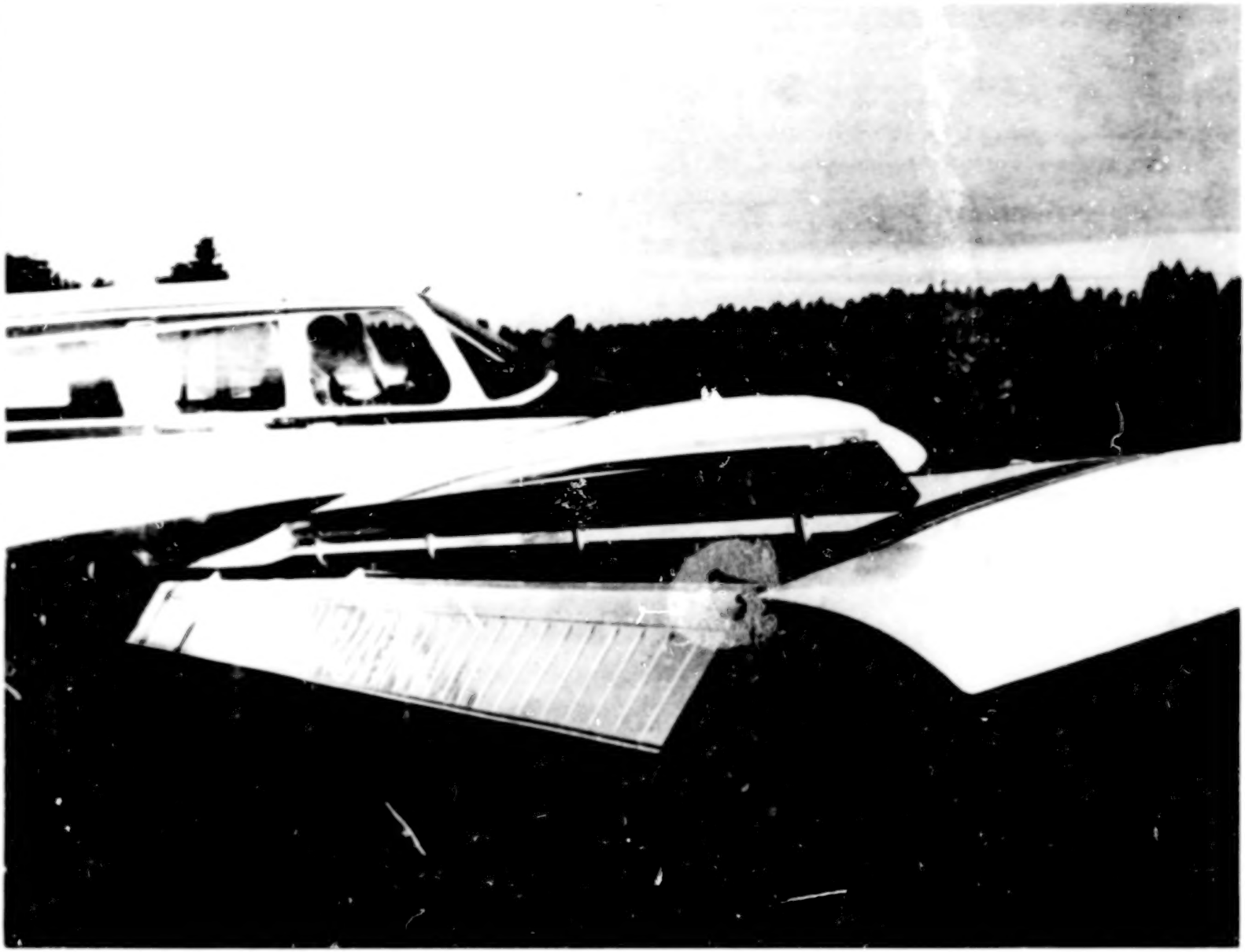


Figure 3.3 Robertson-Seneca with Flaps and Spoilers fully Deflected

Figure 3.4 Full Span Fowler Flaps on the Robertson-Seneca

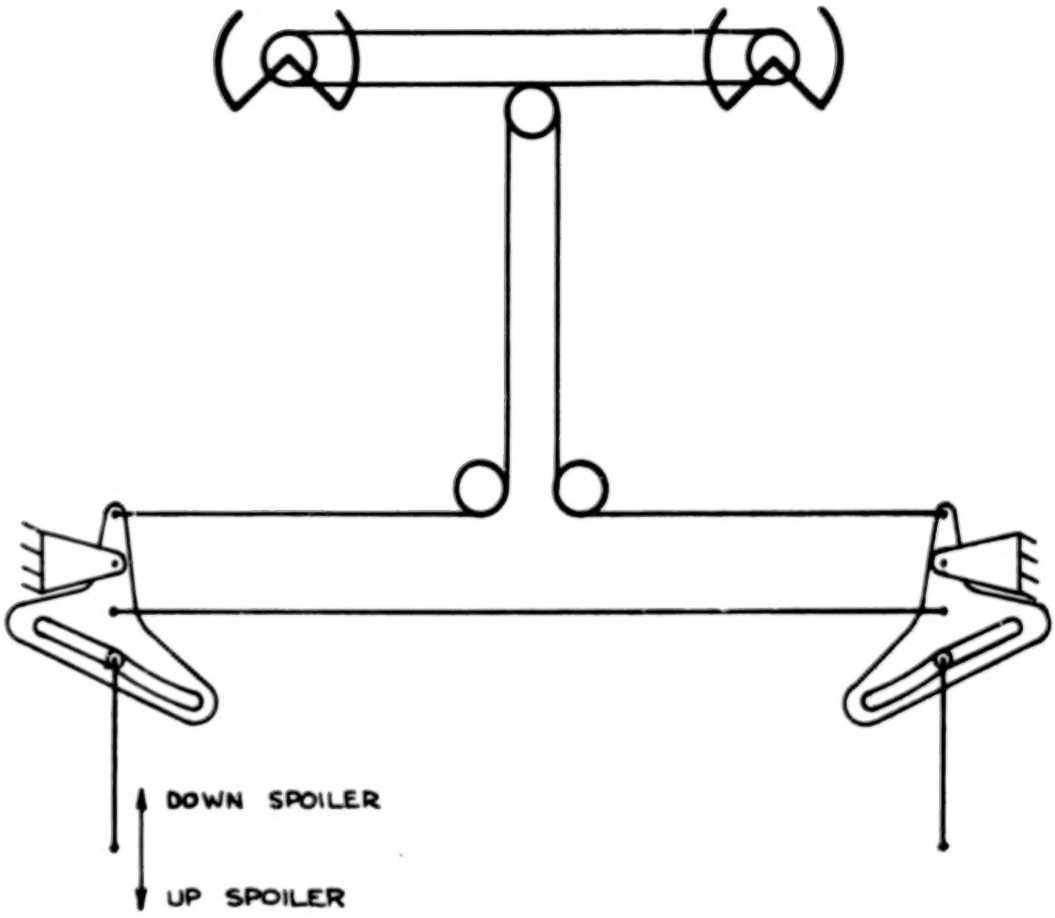


Figure 3.5. Schematic of Spoiler Control System

4. Instrumentation

The data acquisition system was designed and built by the Flight Research Laboratory of CRINC. The entire package, with the exception of the remote transducers, is shown in Figure 4.1, mounted in the seat attachment points for the middle row of seats.

The following data were recorded by a Honeywell Visicorder:

Roll angle, ϕ

Pitch angle, θ

Right spoiler deflection, δ_{S_R}

Left spoiler deflection, δ_{S_L}

Control wheel deflection, δ_W

Control wheel force, F_W

Sideslip angle, β

Airspeed, altitude, and flap deflection were manually recorded at the beginning of each test point. The pitch rate was to be recorded using a rate gyro. However, an early failure of the gyro resulted in roll rates being determined by measuring the slope of the ϕ vs time trace.

Wheel forces were determined with the use of a strain gaged force wheel installed on the right side, Figure 4.2. Spoiler position was determined by means of a potentiometer connected to each spoiler at its midspan position. A sideslip vane and swiveling pitot-static tube were mounted on a boom attached to the left wingtip, Figure 4.3. Previous tests verified that the airspeed position error was negligible with this installation.

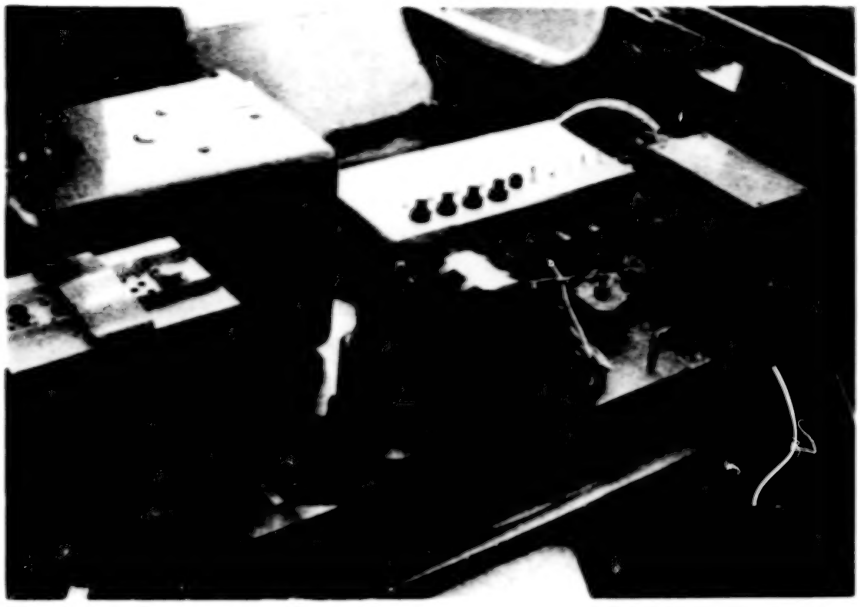


Figure 4.1 - Flight Test Data
Acquisition System

Figure 4.2 - Force Measuring Wheel
Installed in Robertson Seneca

Figure 4.3 - Instrumentation Boom
Installation with β Vane and Swiveling
Pitot-Static Tube

5. Spoiler Roll Characteristics

Four separate flights were conducted to determine the performance characteristics of the Robertson/Seneca Spoiler System. The great majority of the data points were determined by initiating a steady state roll from straight and level flight at a predetermined airspeed. It was found that this technique reduced data scatter and permitted roll entry at repeatable angles of attack. Steady state roll rates were achieved very rapidly so sideslip induced by roll angle was a negligible factor. Elevator angle was held constant during the roll and no rudder inputs were made. At each airspeed and flap position, two rolls from $\pm$ 30° to $\mp$ 30° roll angle were made, one in each direction, with full wheel deflection. Although these data had considerable scatter, they in general verified the trends established by rolls from straight and level flight.

Table 5.1 is a matrix of all the combinations of airspeed and flap deflection for which data were obtained.

Table 5.1. Flight Conditions for Roll Tests

Flap Deflection Deg.	Calibrated Airspeed, knots			
0	75	92	108	136
10	70	-	106	132
20	65	94	109	-
40	63	76	-	-

Figures 5.1 through 5.4 present roll results as roll helix angle versus spoiler angle for each airspeed and flap setting. Fig. 5.5 summarizes the data for each flap setting and shows the effect of airspeed on spoiler effectiveness. Fig. 5.6 compares spoiler effectiveness at low airspeed for the four flap settings tested. Fig. 5.7 provides a correlation between airspeed and airplane lift coefficient at the average test weight of 17,348 newtons (3900 lb). Actual weight was never more than ± 444 newtons (100 lb.) from this nominal value.

Several conclusions may be drawn from these data. At low flap settings (δ_f = 0° and δ_f = 10°) spoiler effectiveness increases as airspeed increases and lift coefficient and angle of attack decrease. However for $\delta_f \geq 20°$ spoiler effectiveness appears to be virtually independent of lift coefficient over the range tested.

It should be noted that the cable stretch characteristics of the system limited the maximum spoiler deflection at high airspeeds. Examination of the data reveals that the helix angle, pb/2V, achieved with maximum wheel deflection is almost independent of airspeed for a given flap deflection because of this cable stretch limitation on spoiler deflection.

Another important characteristic is the significant increase in maximum spoiler rolling moment as the flaps are deflected. Maximum rolling moment coefficient with δ_f = 40° is 2.64 times that obtained with δ_f = 0°. Thus at low airspeeds in the landing configuration, where conventional aileron control becomes sluggish, the spoiler

system can provide actual roll rates as high or higher than cruise roll rates.

To convert these data from helix angle, pb/2V, to rolling moment coefficient, C_ℓ, a useful form for comparison with wind tunnel data and theory, the following formula is used. In a steady state roll

$$C_\ell = \frac{-C_{\ell_p}(pb)}{2V_T}$$

A detailed analysis using Ref. 10 showed that $C_{\ell_p} = -.476$ for the Robertson Seneca for all flap settings. Thus to convert these data to rolling moment coefficient due to spoilers,

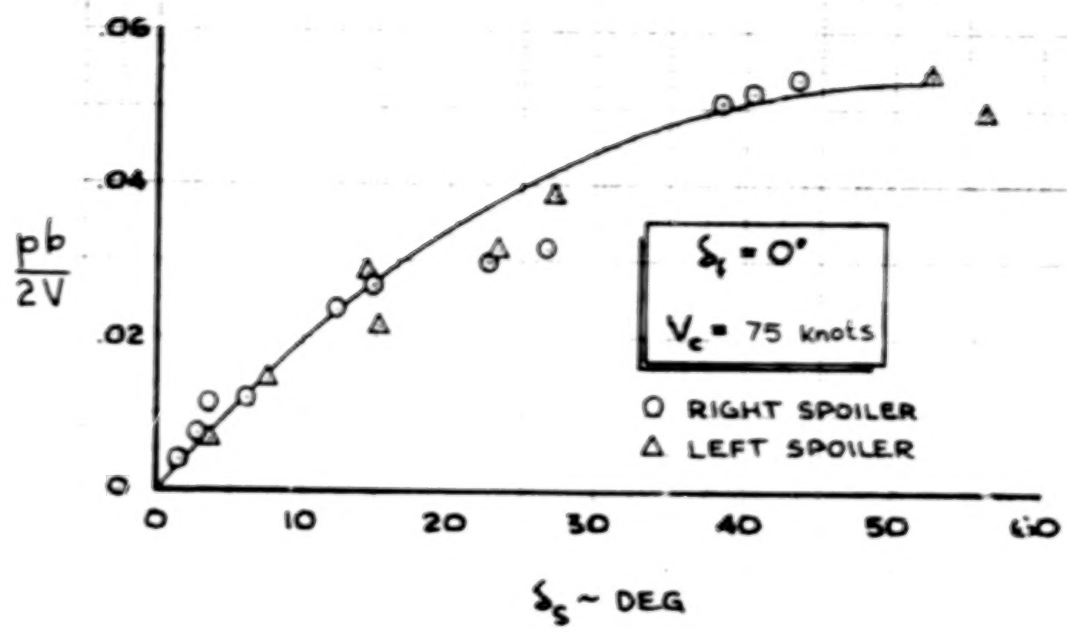
$$C_\ell = -.476 \frac{pb}{2V}$$

For all flap settings and airspeeds there is no deadband or reduced sensitivity at low spoiler deflections. For $\delta_f = 40^\circ$, the spoilers are biased up several degrees. In flight, pb/2V = 0 with $\delta_s = 2.4^\circ$. The bias was introduced primarily to eliminate decentering aerodynamic loads. However, because the biased setting results in one spoiler going down while the other goes up over the first ten degrees of spoiler travel, the initial roll sensitivity for $\delta_f = 40^\circ$ is very high, about double that which would exist with no bias. This increased sensitivity is clearly evident in Figure 5.6.

Although spoiler rolling moment is a monotonic function of spoiler angle, δ_s, it is not linear except for small angles. The decrease in $C_{\ell_{\delta_s}}$ at large spoiler deflections is not particularly

noticeable or bothersome to the pilot. Actually, theory indicates that C_ℓ should be a linear function of spoiler height, h, rather than angle, δ_s. Fig. 5.8 plots the data of Fig. 5.6 as a function of h/c. Although the spoiler effectiveness is more nearly linear as a function of h/c there is a decrease in effectiveness, $\partial C_\ell / \partial (h/c)$, for large deflections as would be expected. It may be observed in Figs. 5.1 - 5.4 that there appears to be a consistent difference between the effectiveness of the right and left spoilers, particularly for large spoiler deflections. It is believed that this difference is probably due to a minor calibration error rather than any aerodynamic differences. In any case the difference is not large, and is negligible for $\delta_s \leq 15^o$.

The qualitative yaw characteristics of the spoilers were determined by recording the sideslip angle, β, during each of the roll maneuvers. Figs. 5.9 through 5.12 show time histories of four representative roll maneuvers at various flight conditions. Note that there is no discernible immediate response in yaw due to a step spoiler input, although β does increase gradually as the roll angle increases, a result of the side force due to gravity. However, in no case does the yaw angle become more than one or two degrees. Thus it appears that yawing moment due to spoiler, $C_{n_{\delta_s}}$, is very nearly zero for all flap settings and airspeeds tested.



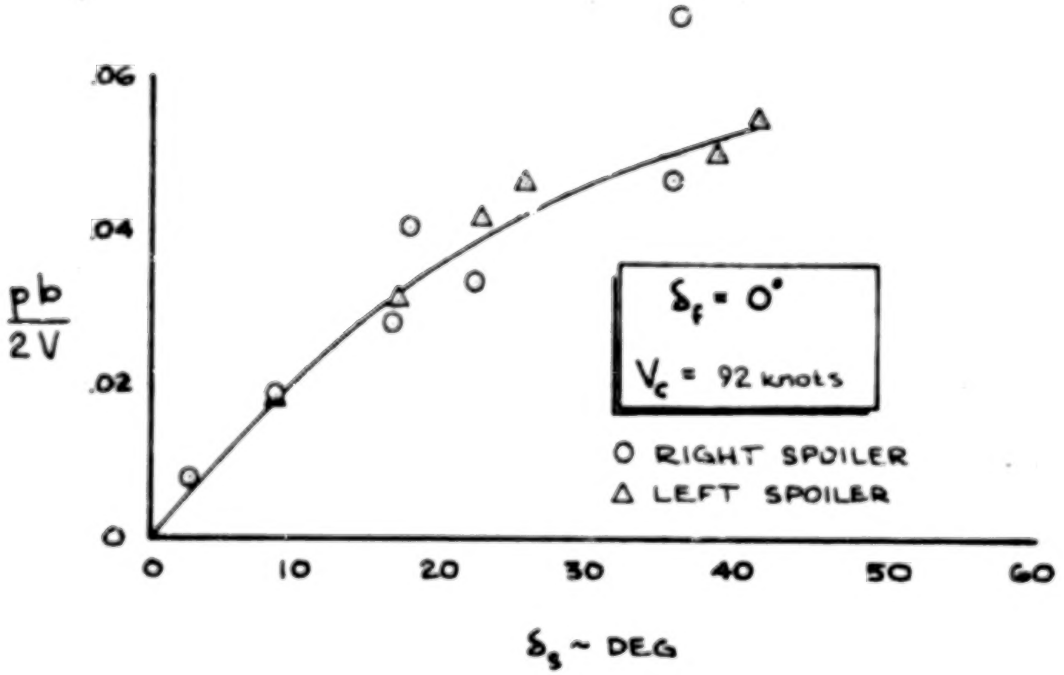
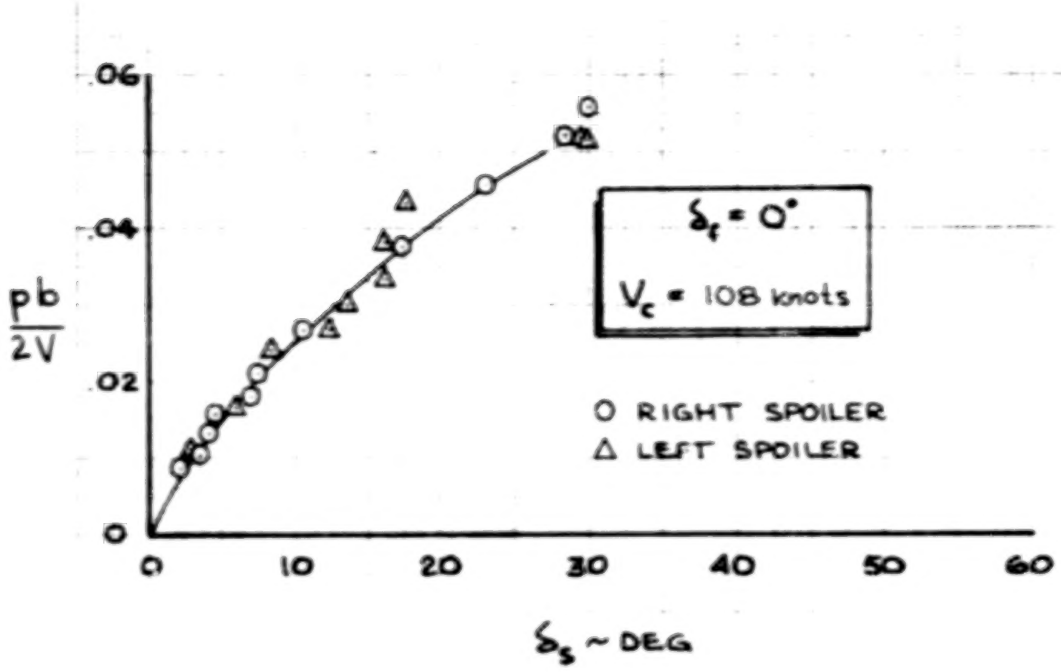
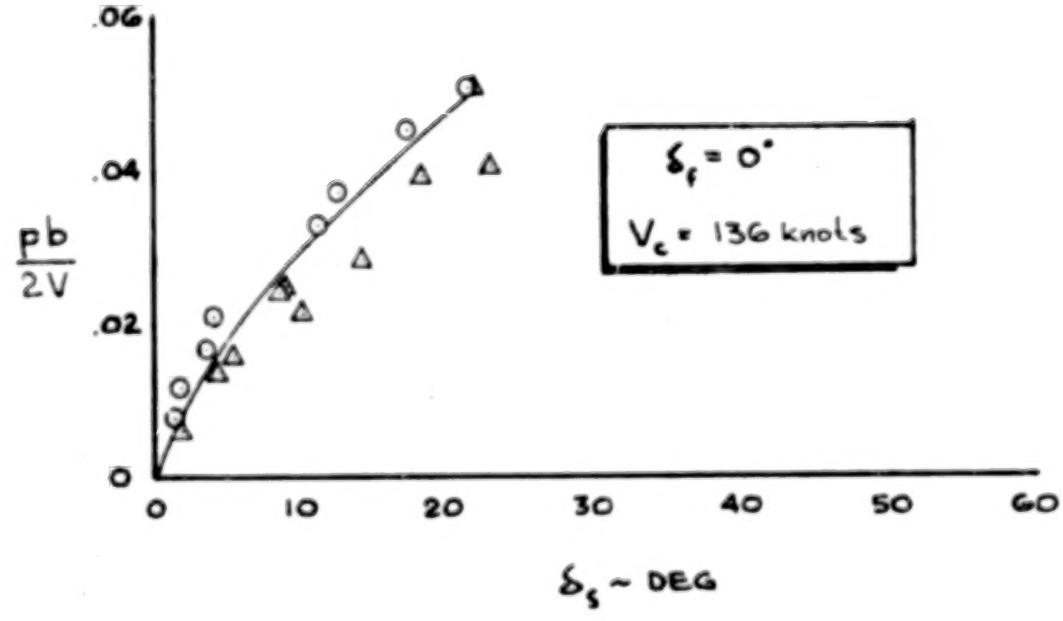


Figure 5.1 - Roll Performance with Spoilers, $\delta_f = 0^o$





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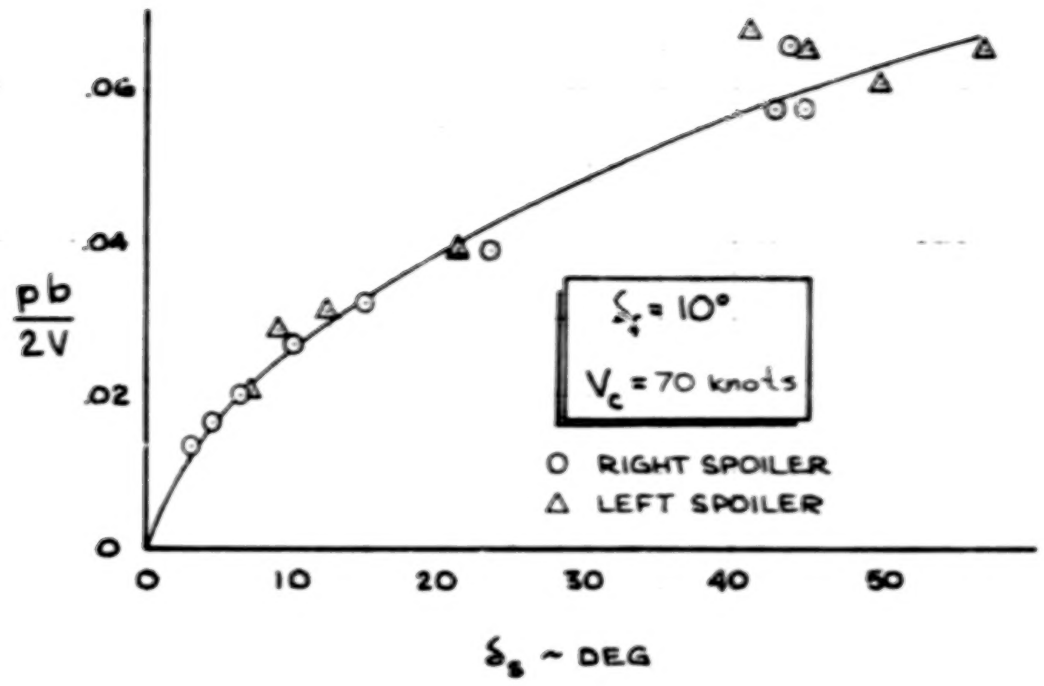


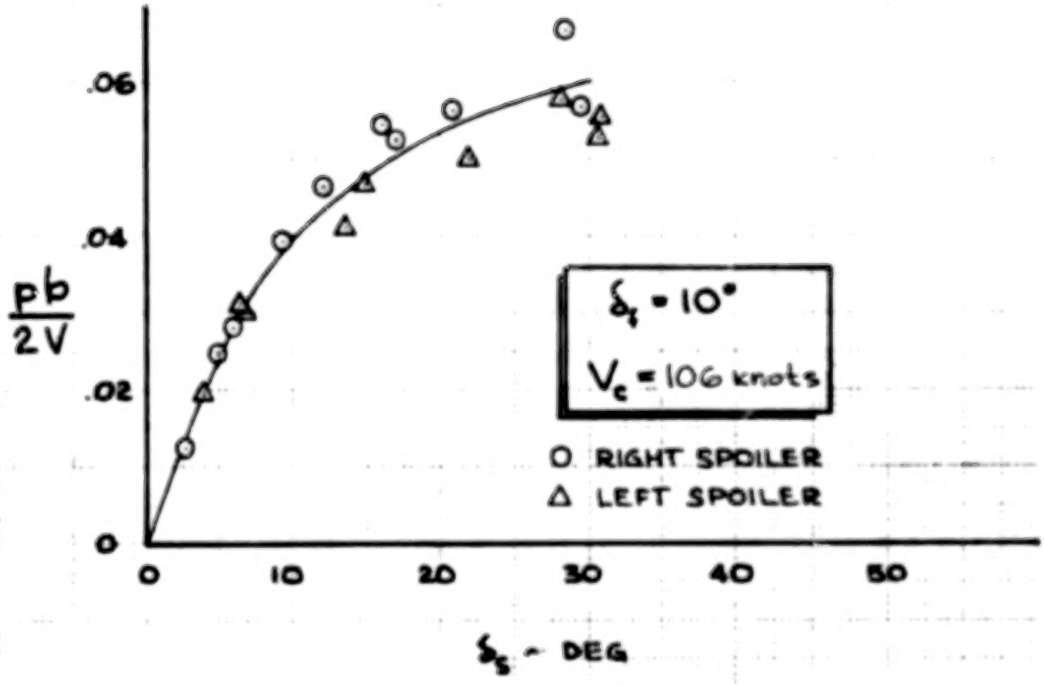


Figure 5.2 - Roll Performance with Spoilers, $\delta_f = 10^0$

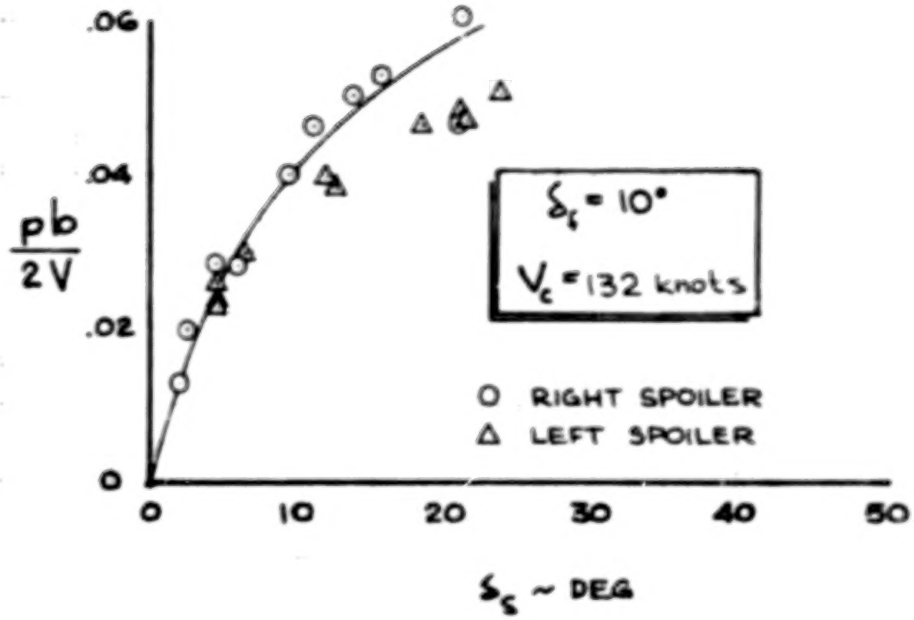


Figure 5.2 - Continued

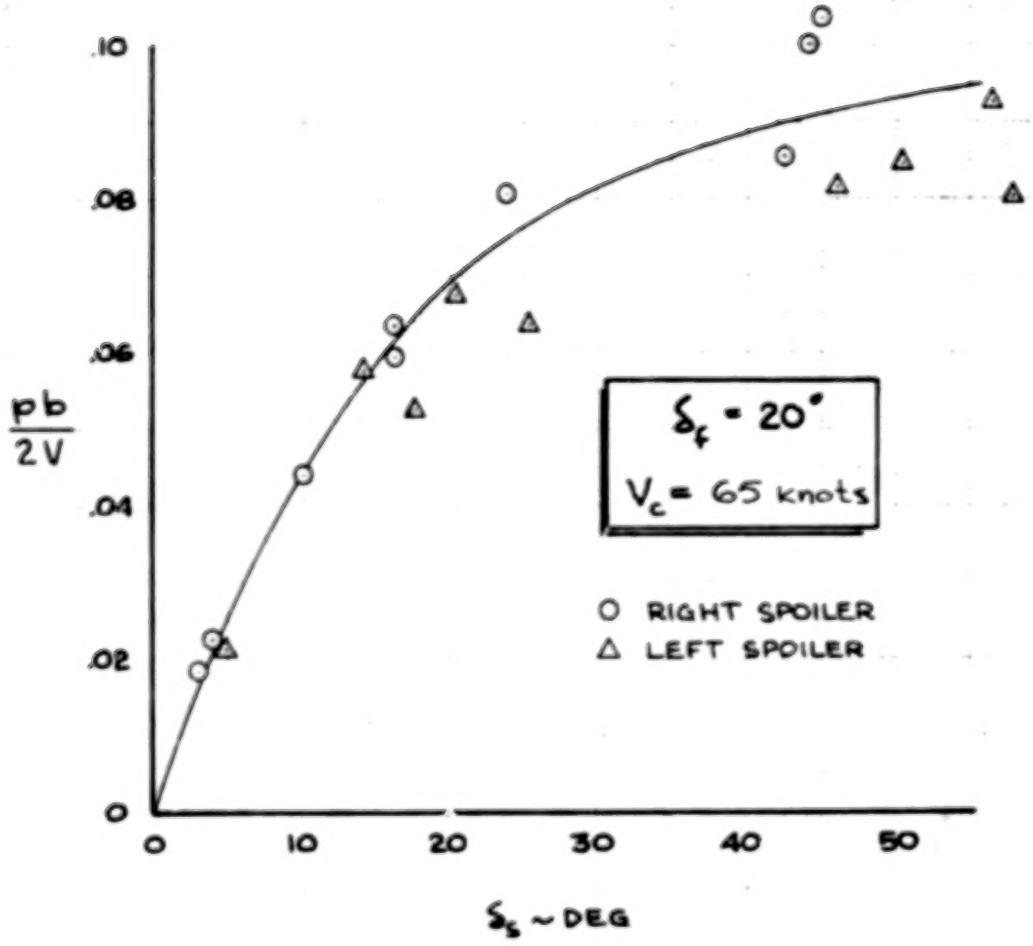
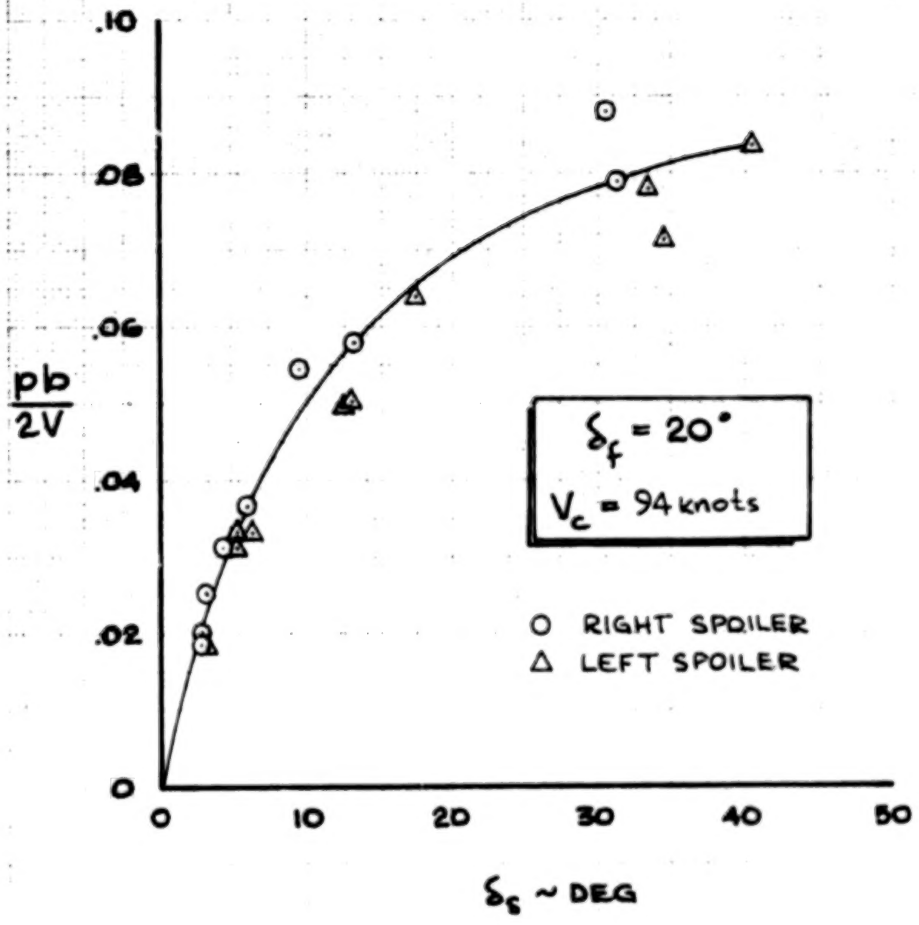


Figure 5.3 - Roll Performance with Spoilers, $\delta_f = 20^0$



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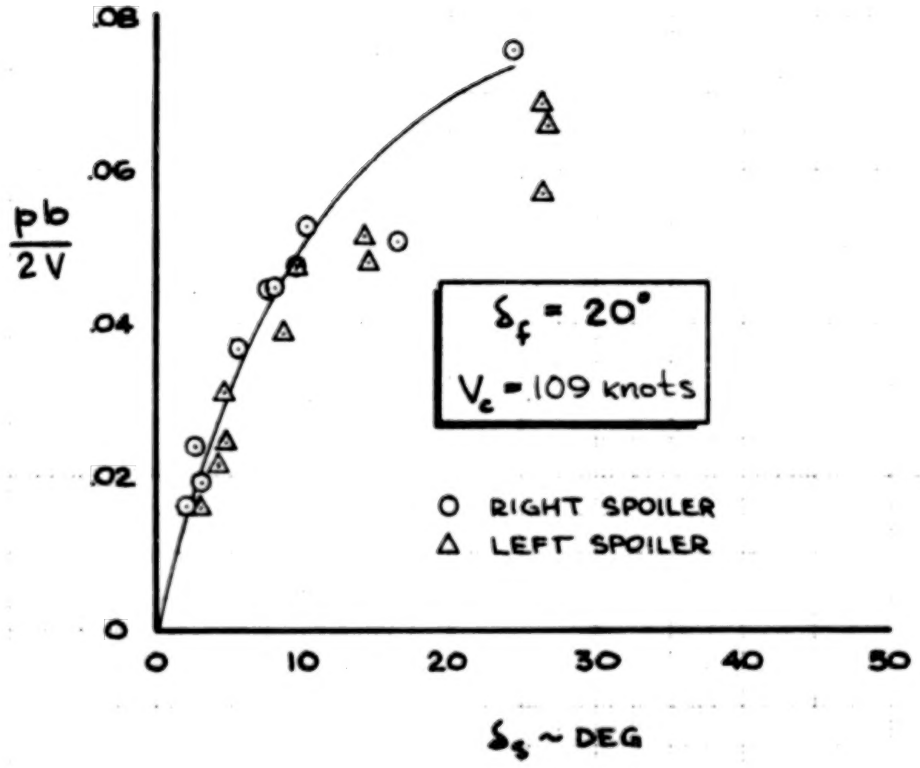

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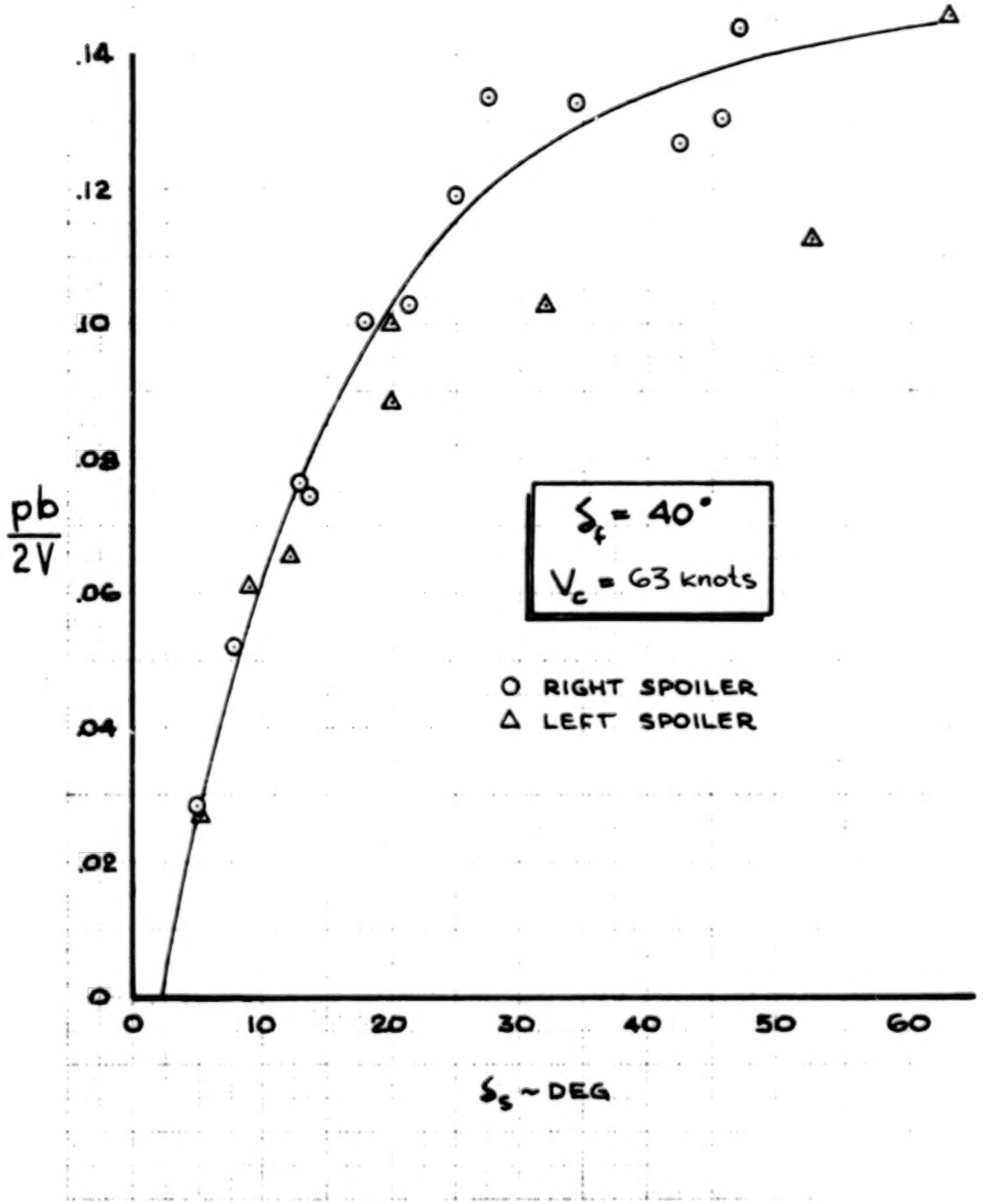
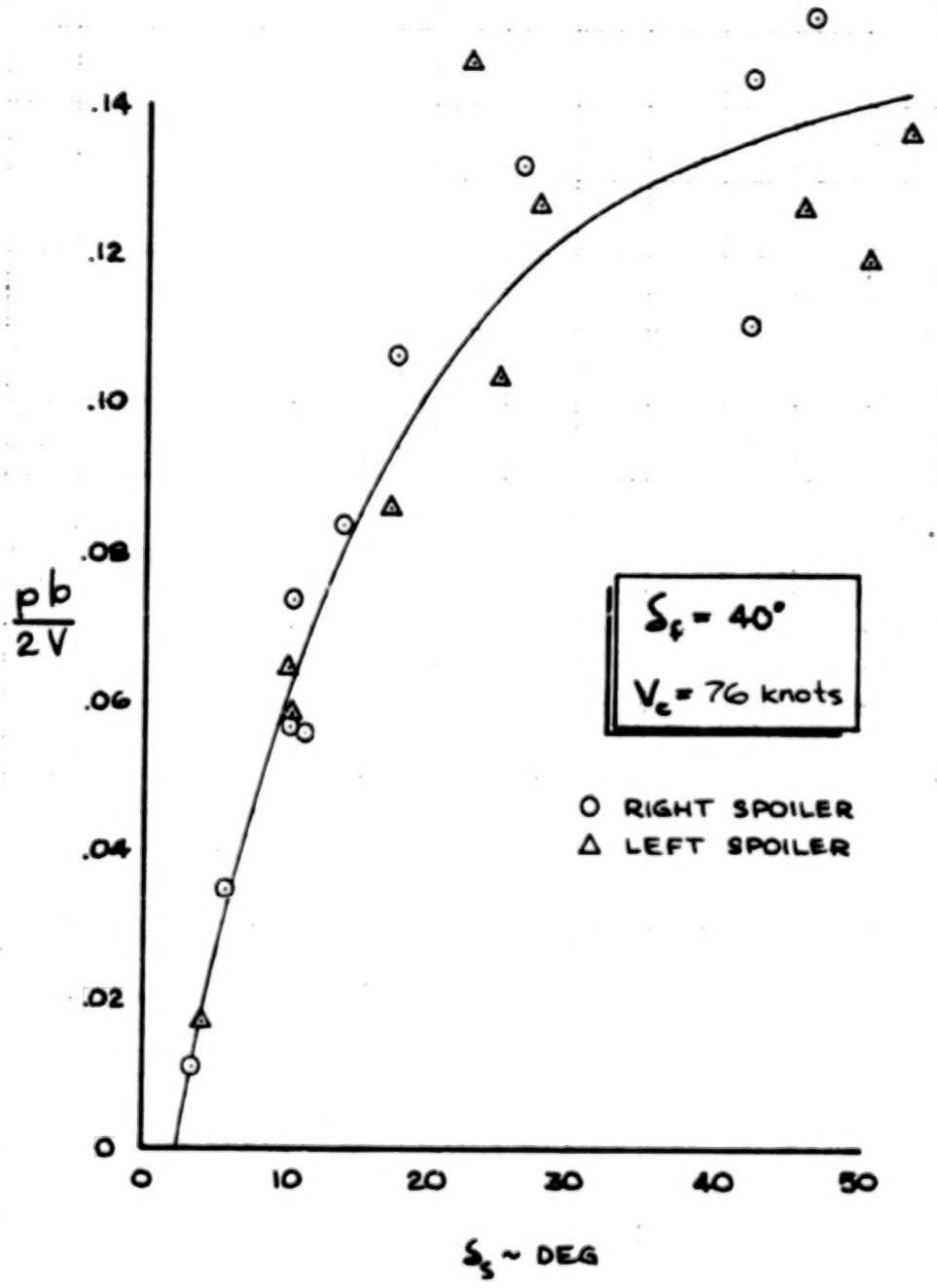


Figure 5.4 - Roll Performance with Spoilers, $\delta_f = 40^\circ$



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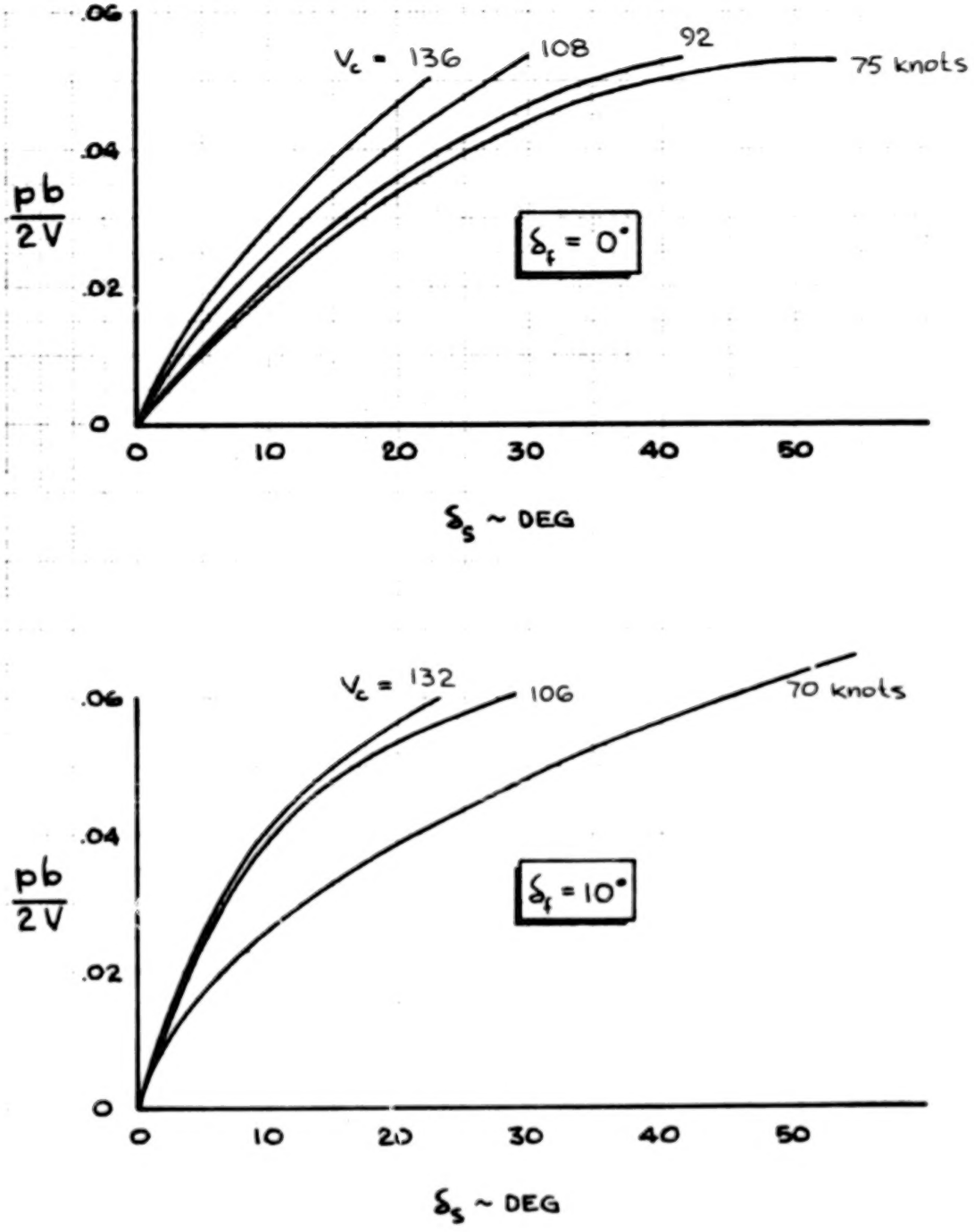
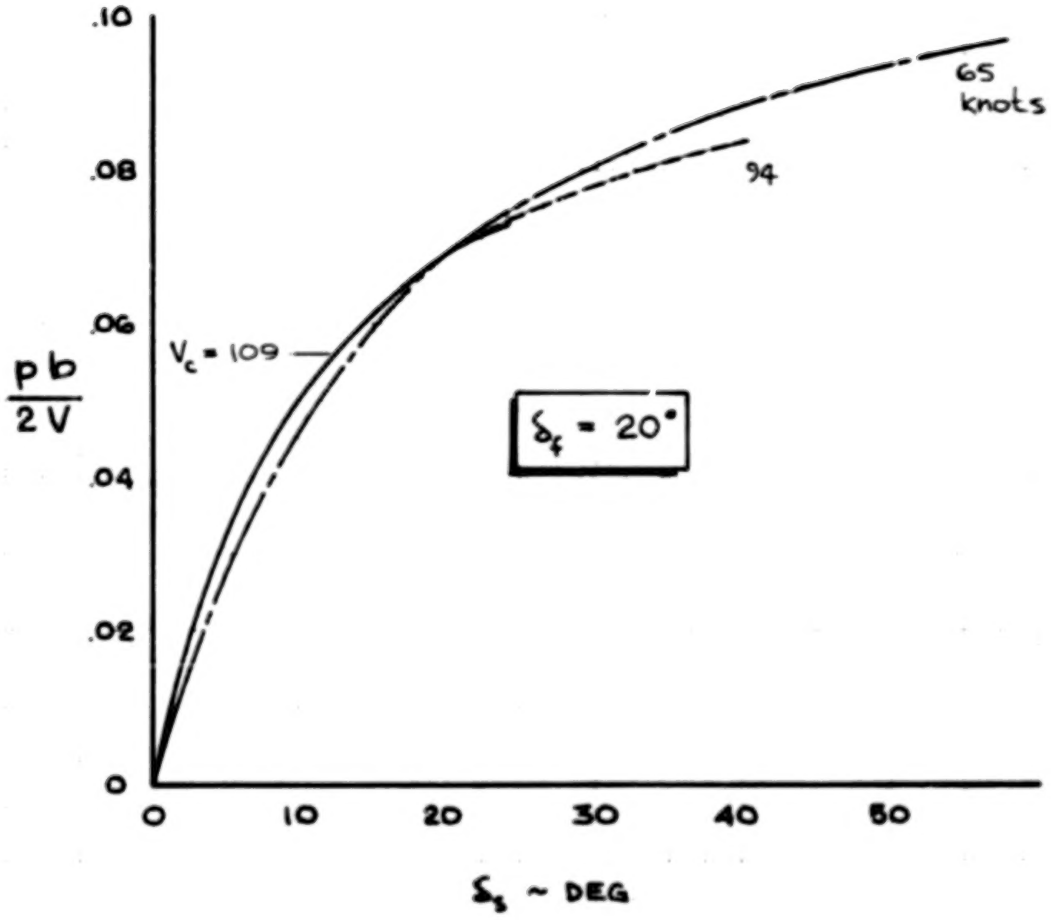


Figure 5.5 - Summary of Roll Performance with Spoilers



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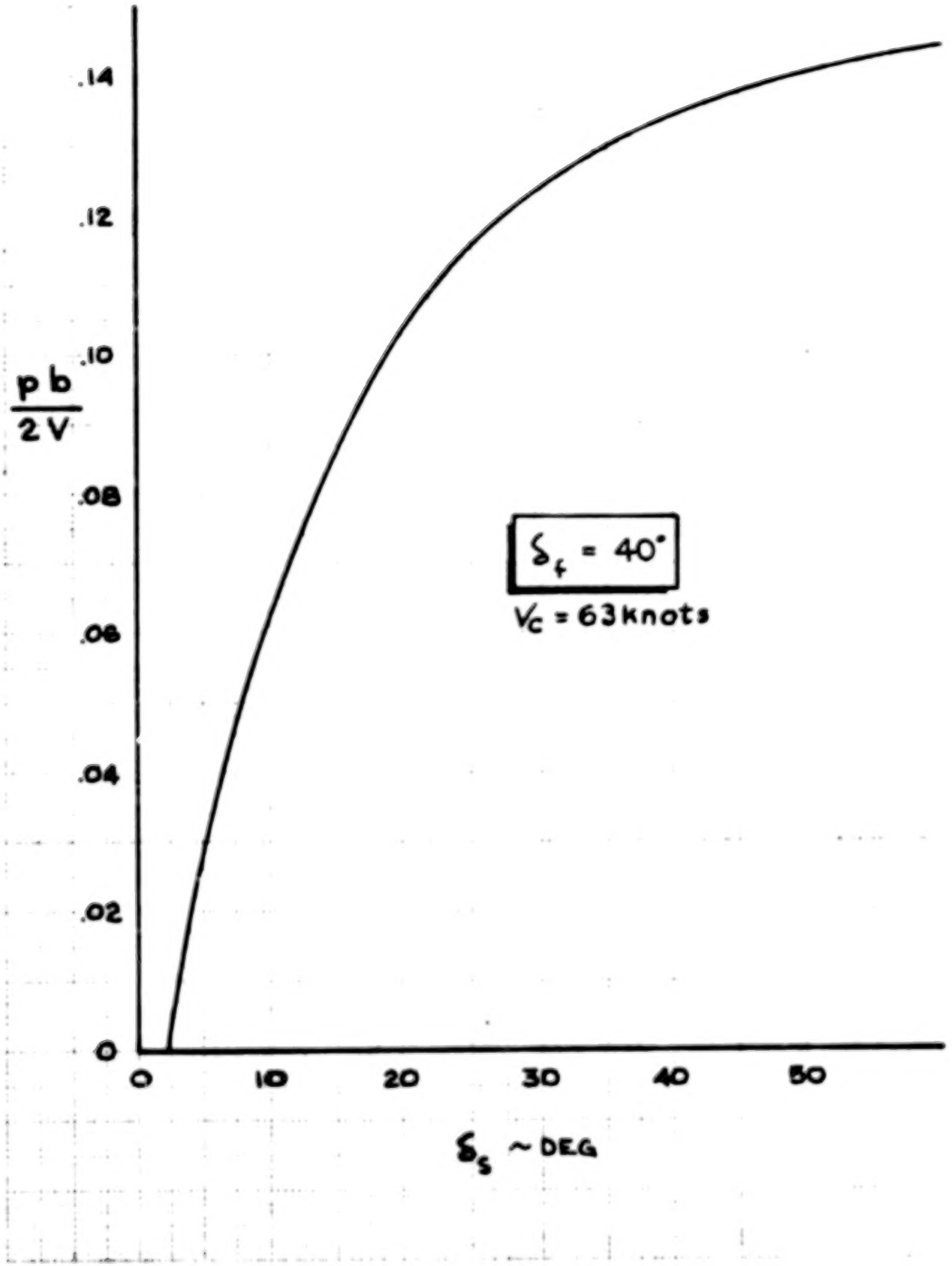

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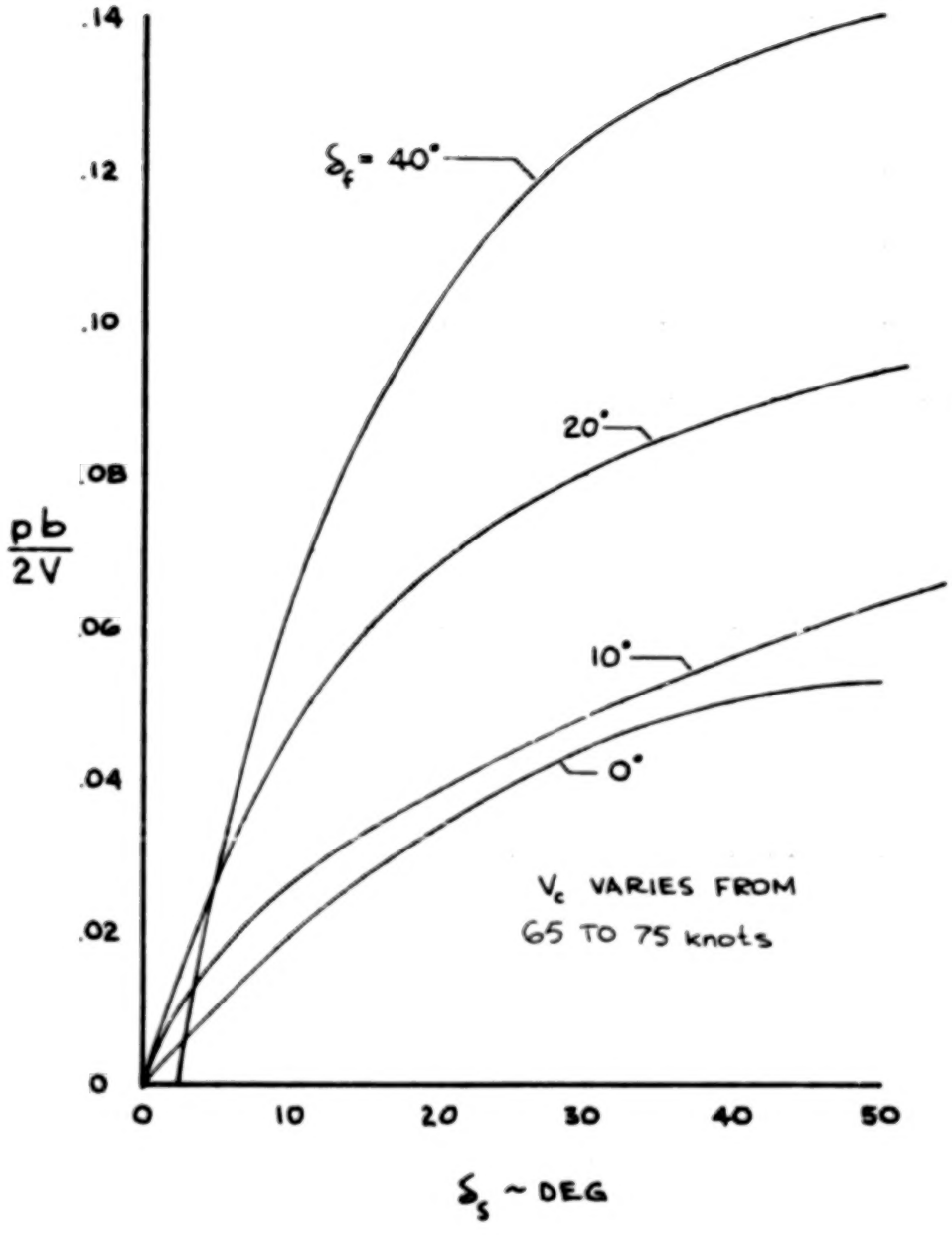

Figure 5.6 - Effect of Flap Setting
on Roll Performance with Spoilers

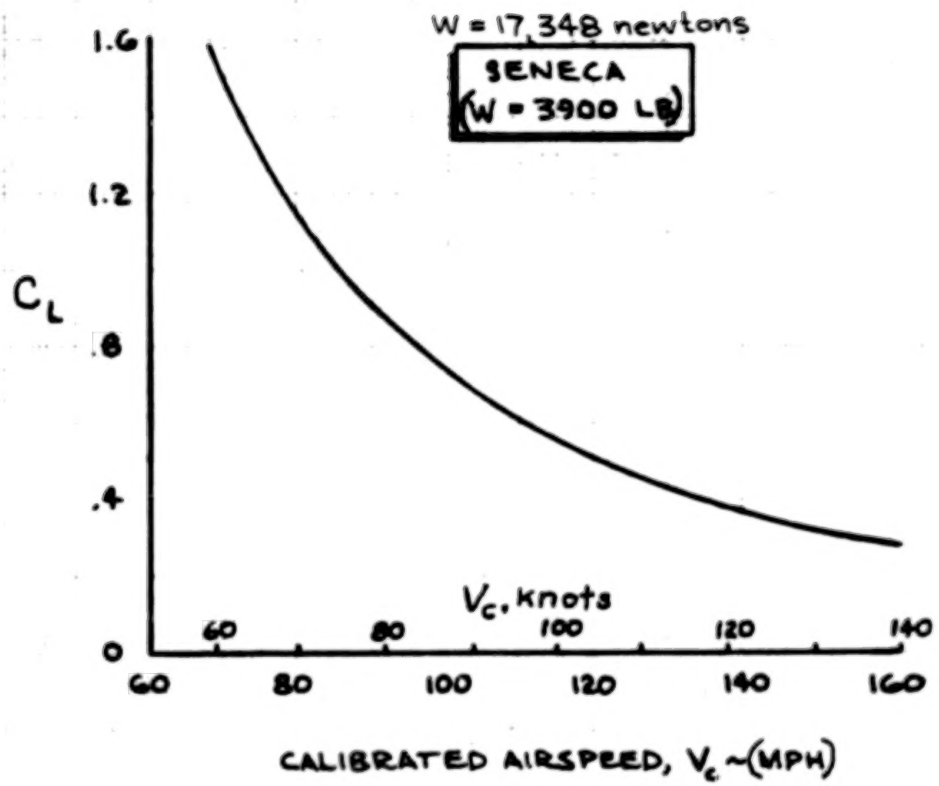

Figure 5.7 - Relationship of Lift Coefficient to Airspeed during Flight Tests

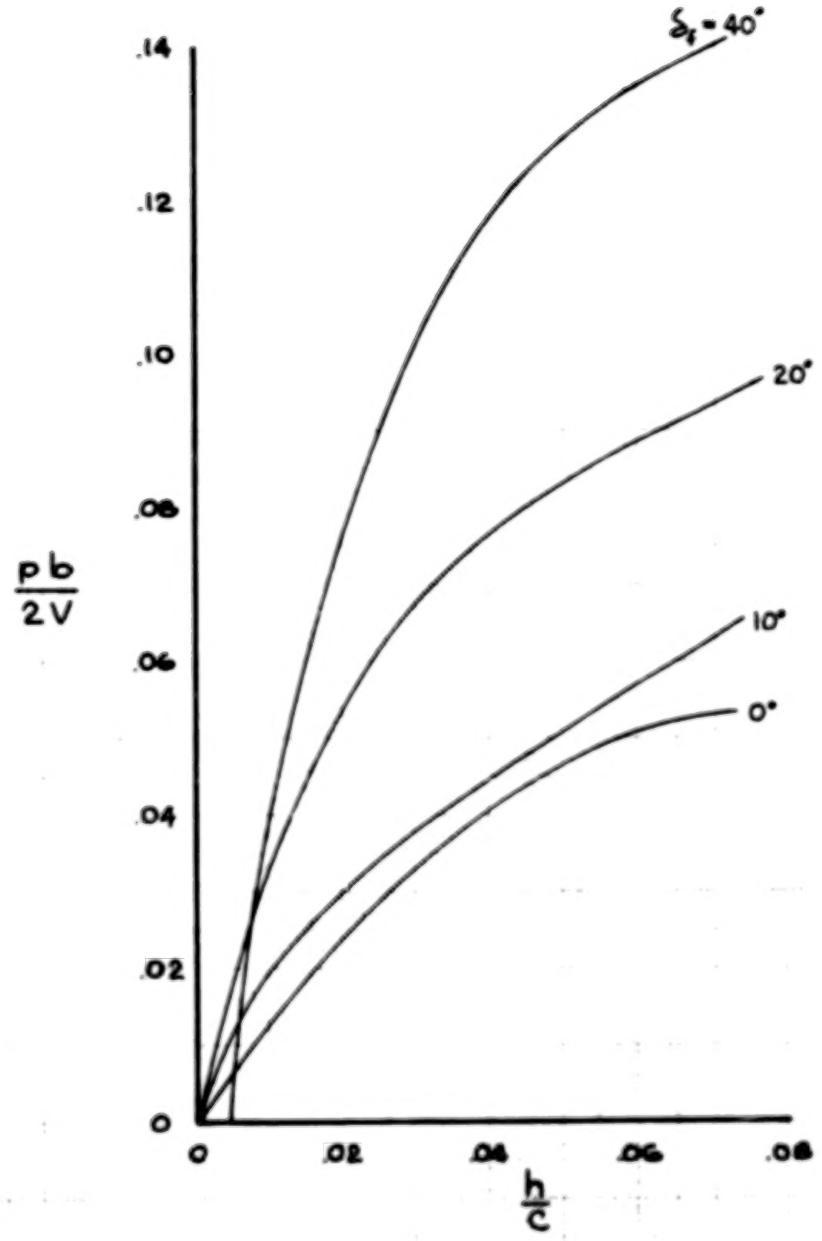

Figure 5.8 - Roll Performance as a Function of Spoiler Height

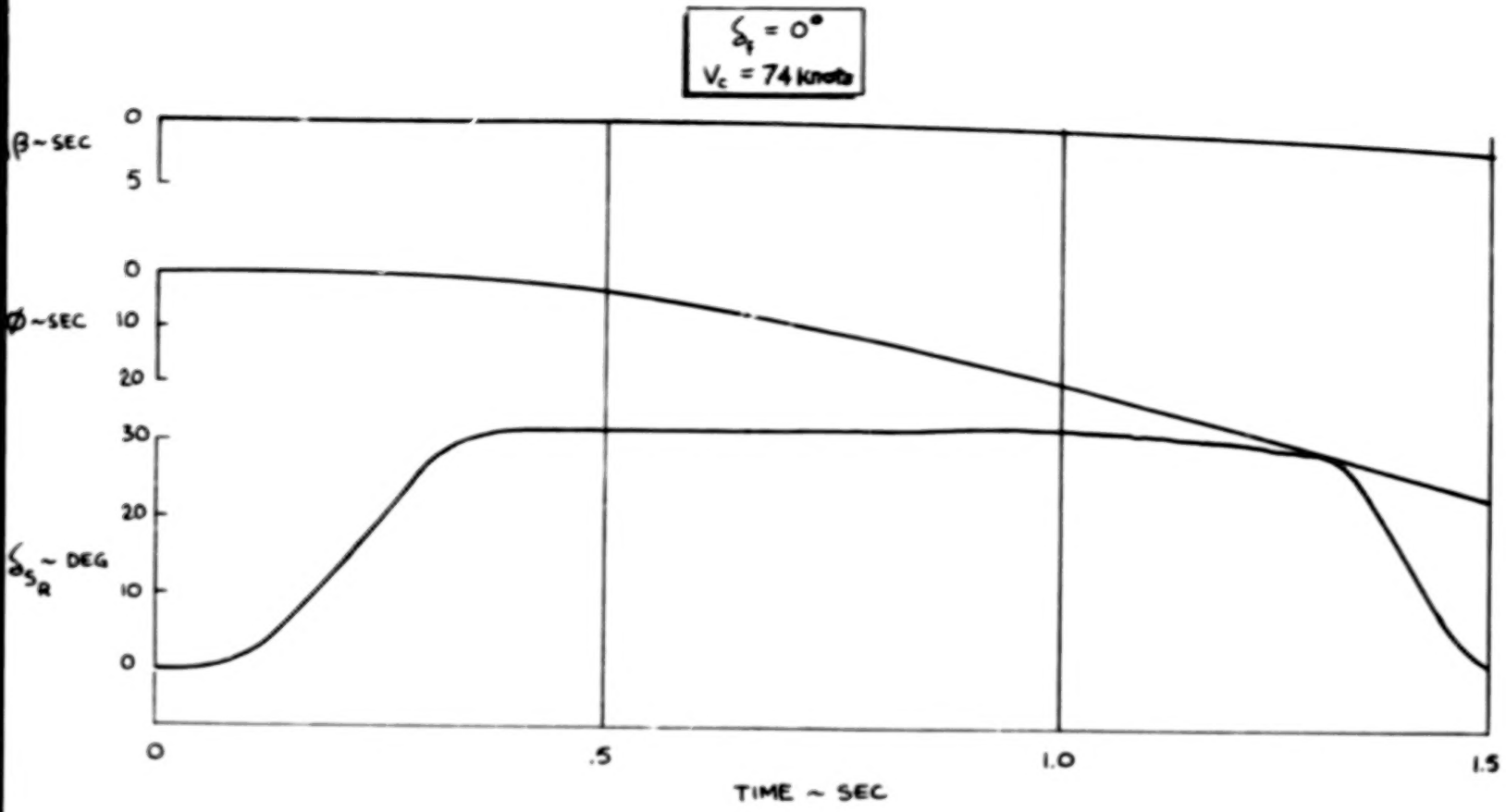

Figure 5.9 - Time History of Roll Maneuver, V_c = 74 knots, δ_f = 0°

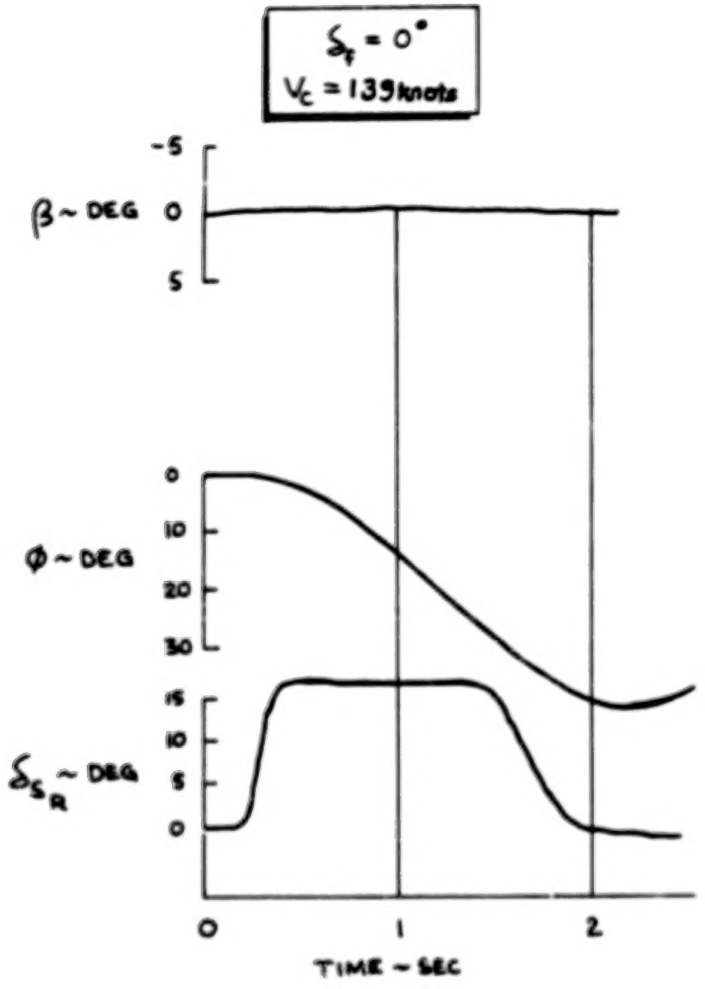

Figure 5.10 - Time History of Roll Maneuver, V_c = 139 knots, δ_f = 0

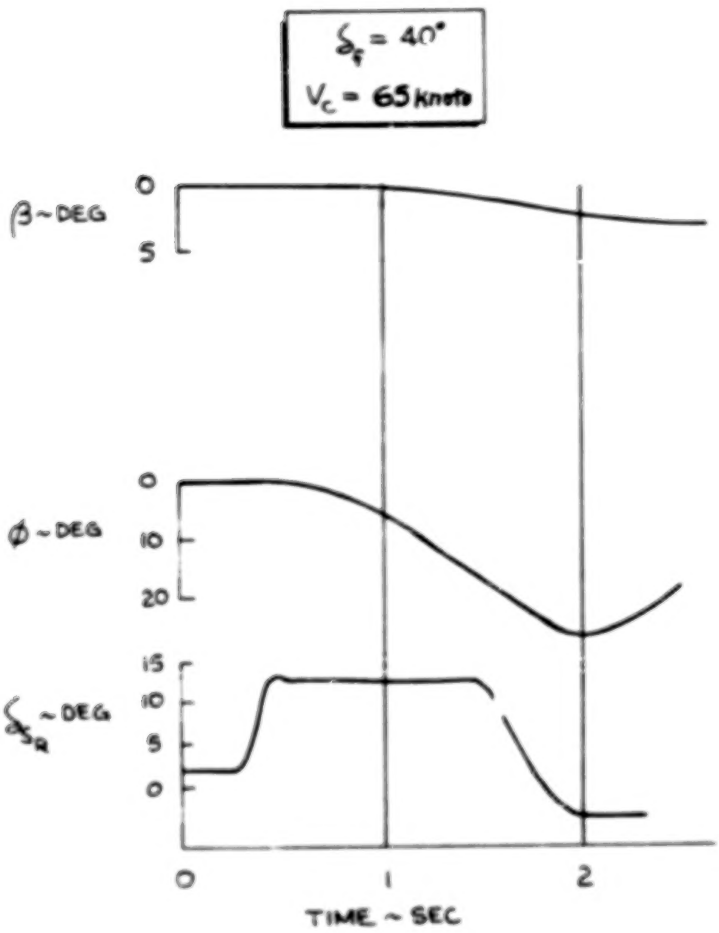

Figure 5.11 - Time History of Roll Maneuver, V_c = 65 knots, δ_f = 40°

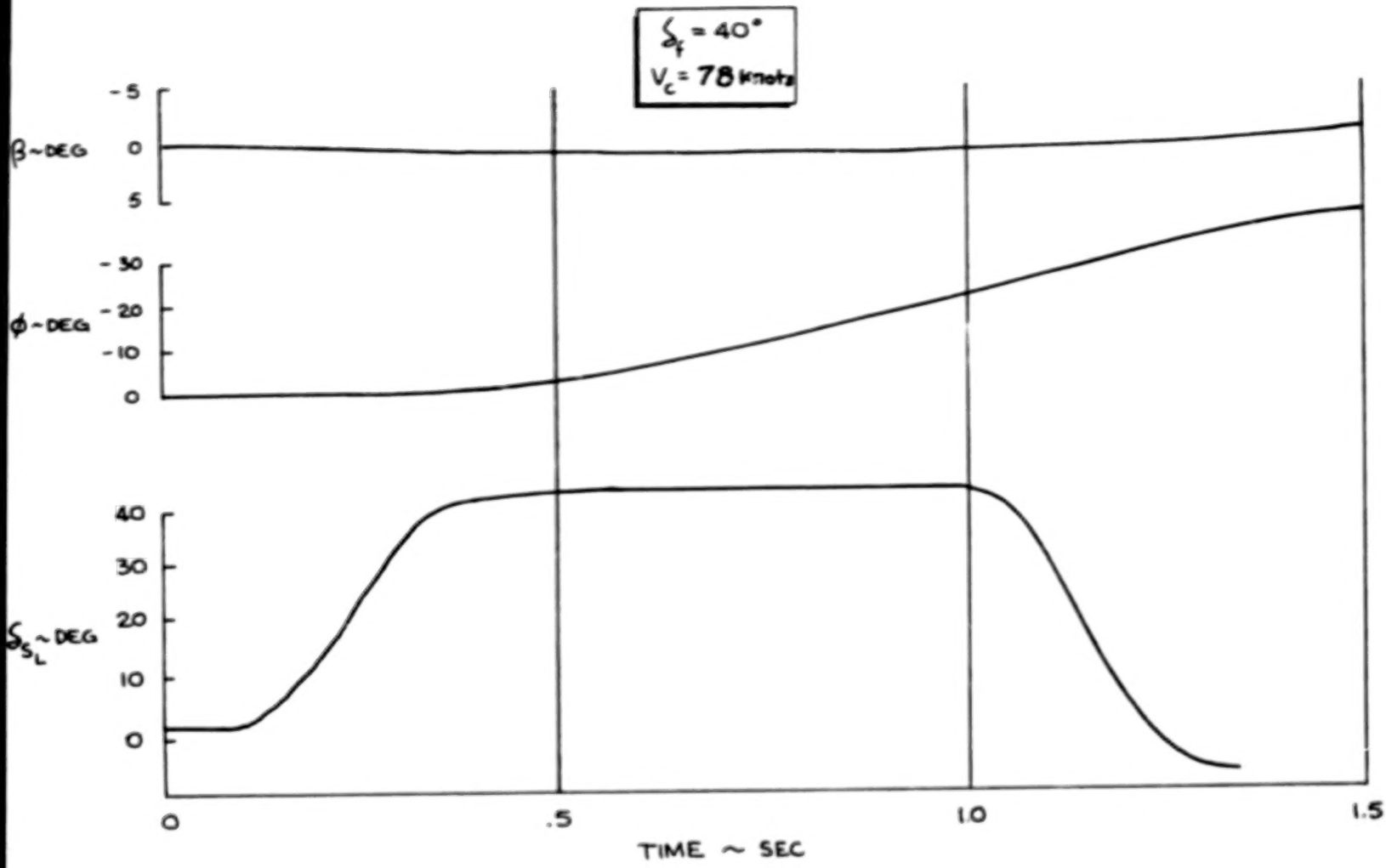

Figure 5.12 - Time Histo y of Roll Maneuver, V_c = 78 knots, δ_f = 40°

6. Wheel Deflections and Forces

Measurements of wheel and spoiler positions were made to determine the inflight relationship and the effect of dynamic pressure on cable stretch characteristics. Figure 6.1 shows the original design for the wheel vs. spoiler deflection. Clearly, there is a significant change as the flaps are lowered, the main effect being a symmetric bias position of 6.3^{o} for both spoilers.

Also shown in Figure 6.1 is the ground position (no airloads) of spoilers as a function of wheel position with $\delta_f = 0^{o}$. There is a difference between the right and left spoiler deflection characteristics due to minor mechanical adjustment differences.

Figures 6.2 through 6.4 show the spoiler deflection characteristics in flight at various airspeeds and flap deflections. It is apparent that the difference between right and left spoiler exists in flight. There is also a considerable amount of cable stretch which seriously limits the maximum spoiler deflection at high speeds. Doubling the airspeed reduces the spoiler deflection for a given wheel position by up to a factor of two.

With the flaps at 40^{o}, the differences between right and left spoiler are much less pronounced. Furthermore, the bias position of the spoilers is reduced to about 2.5^{o} because of airloads at typical approach speeds.

The wheel force data was not complete enough to determine significant trends or accurate hinge moments. The problem was caused both by high friction and breakout forces as well as data recording system problems. However, Figure 6.5 illustrates typical force

characteristics for a flap setting of 20^{o}. The dynamic data exhibits a typical hysteresis loop caused by friction loads.

The effect of airspeed on wheel force is not proportional to dynamic pressure because of cable stretch which reduces the spoiler deflection as airspeed increases.

The forces were generally almost linear with flap deflection and maximum forces were always well within the maximum desired level.

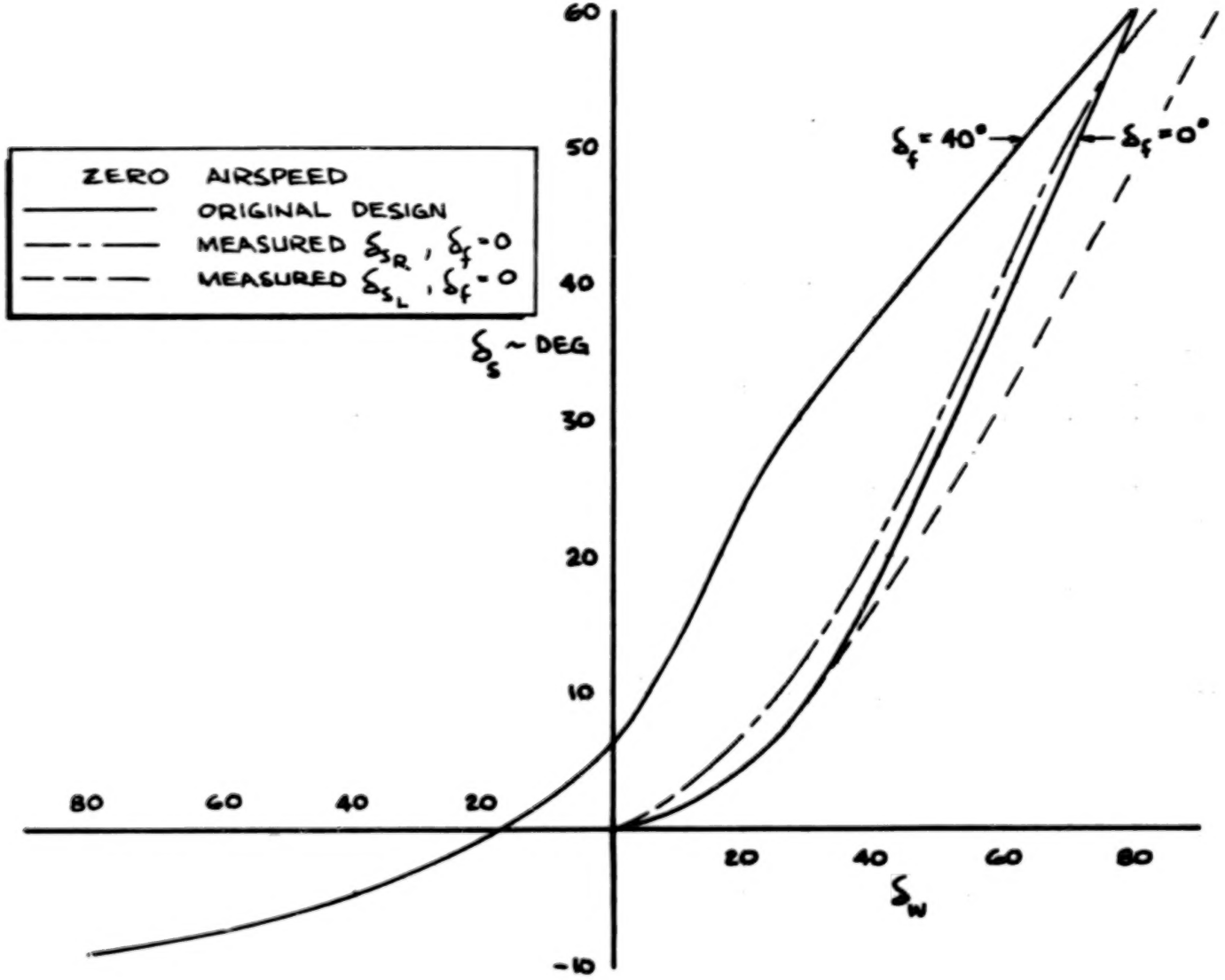

Figure 6.1 - Designed and Actual Relation Between Spoiler and Wheel Deflections

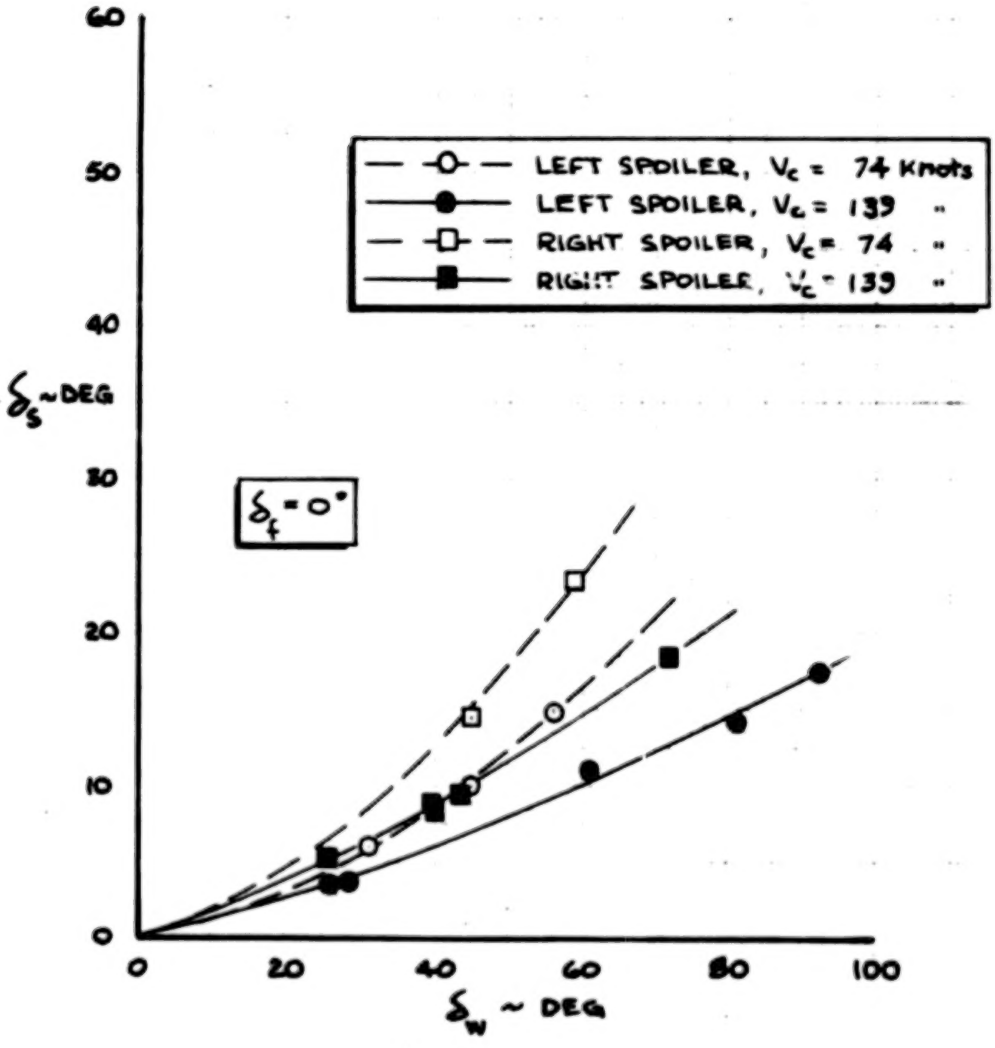

Figure 6.2 - Spoiler Deflection Characteristics, $\delta_f = 0^o$

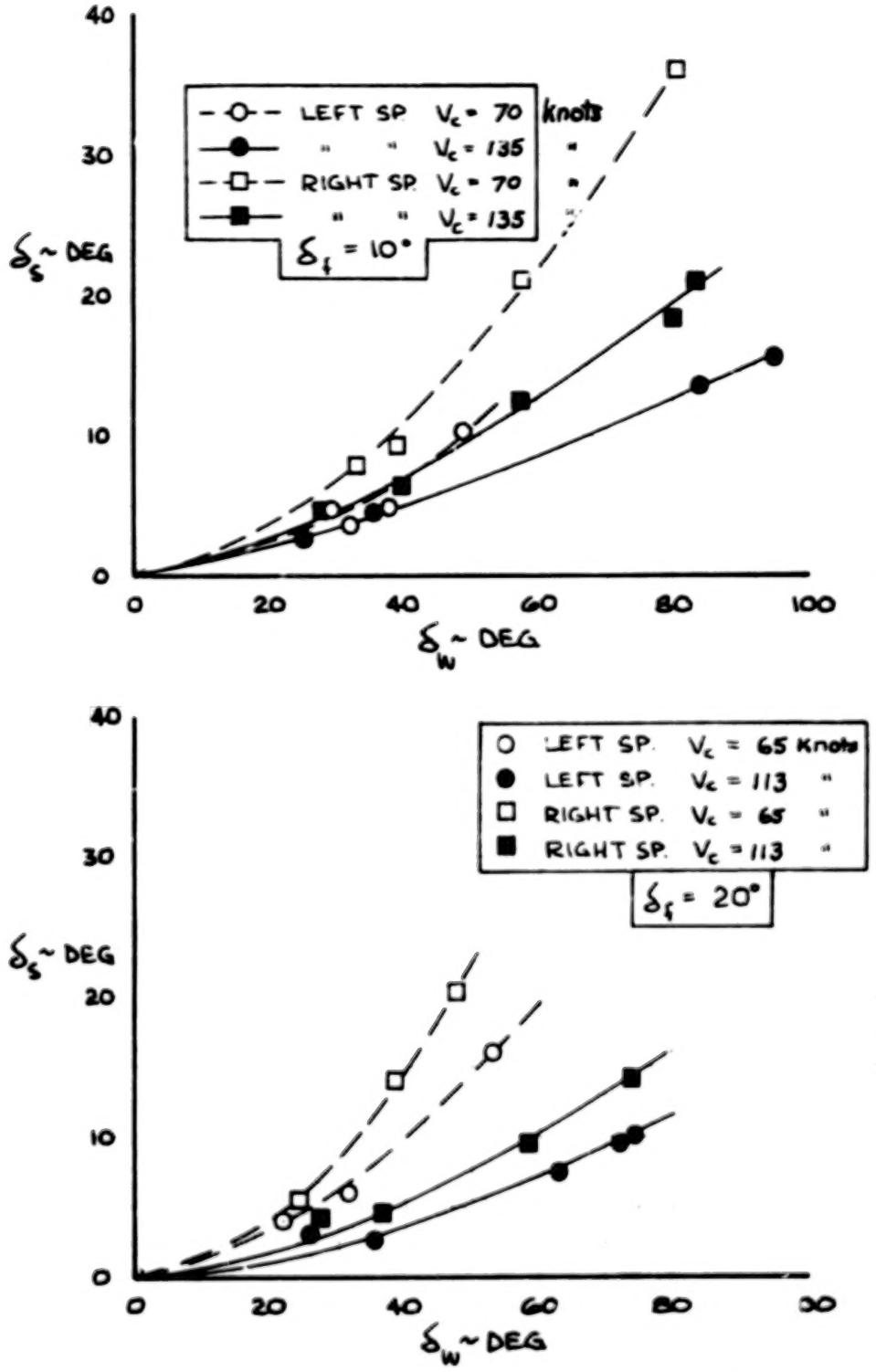

Figure 6.3 - Spoiler Deflection Characteristics, $\delta_f = 10^o$ and 20^o

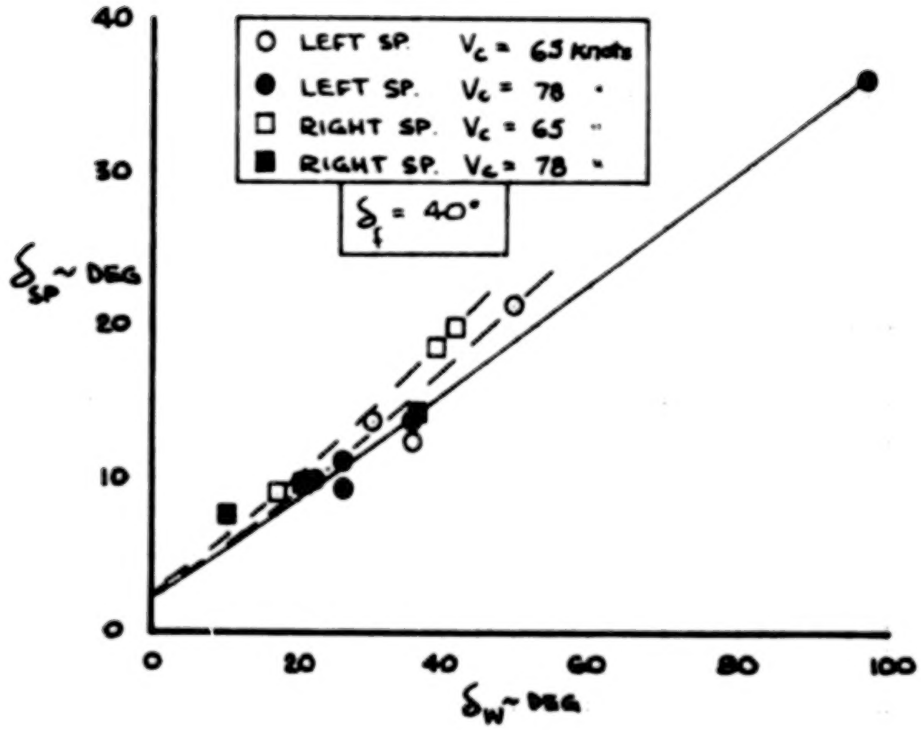

Figure 6.4 - Spoiler Deflection Characteristics, $\delta_f = 40^\circ$

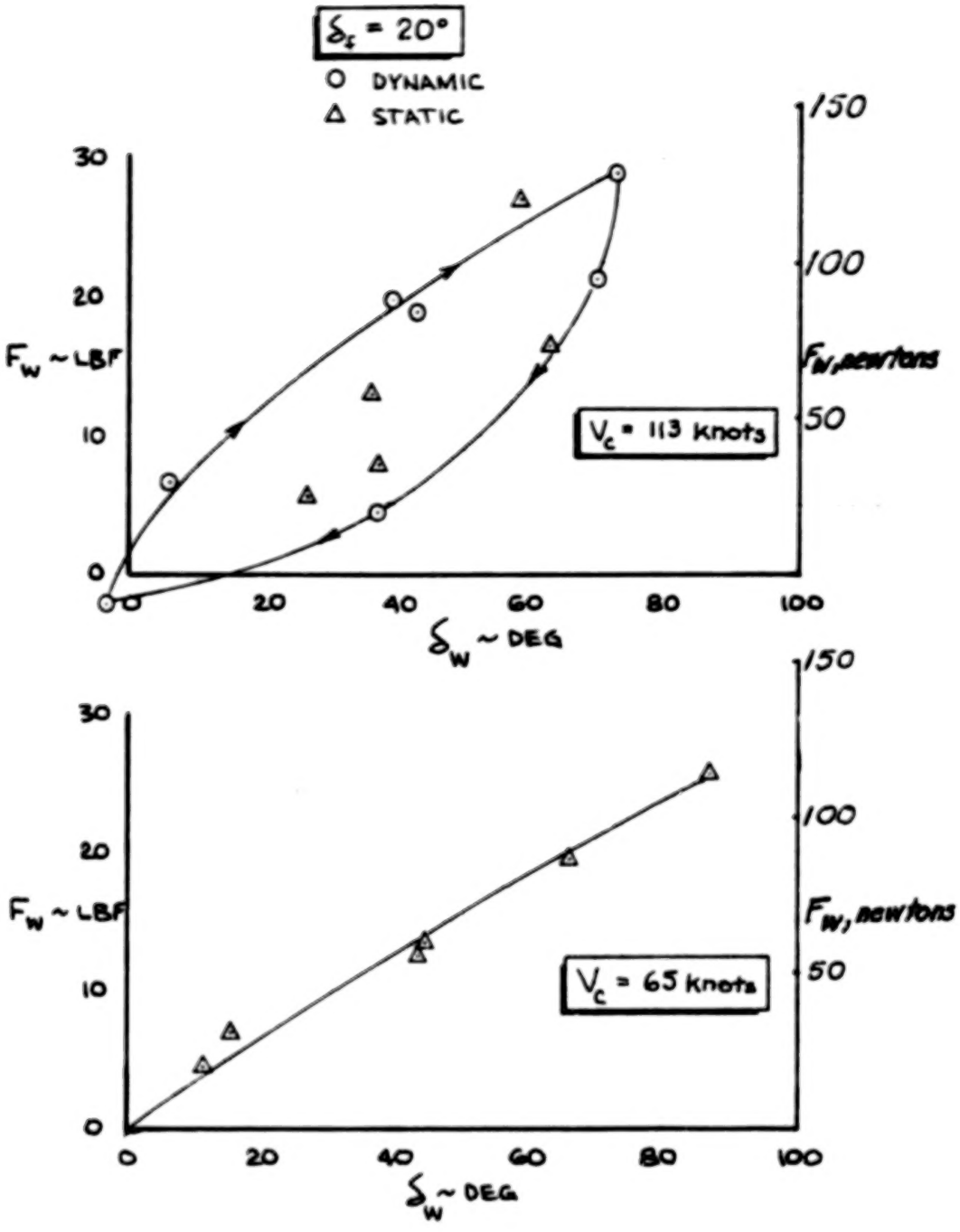

Figure 6.5 - Wheel Force Data for $\delta_f = 20^\circ$

7. Conclusions

1. At low flap settings ($0° \leq \delta_f \leq 10°$) spoiler effectiveness increases as airspeed increases and lift coefficient and angle of attack decrease.
2. For $\delta_f \geq 20°$ spoiler effectiveness is virtually independent of lift coefficient.
3. Maximum spoiler rolling moment coefficient at $\delta_f = 40°$ was 2.64 times that obtained with $\delta_f = 0°$.
4. No deadband or reduced sensitivity at low spoiler deflections was detected.
5. Wheel forces were not excessive for any flight condition or configuration tested.
6. Yawing moment due to spoiler deflection was nearly zero for all flap settings and airspeeds tested.
7. Cable stretch greatly reduced the maximum available spoiler deflection at high airspeeds. A designer must give careful attention to this problem.

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15. Supplementary Notes

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Final Report

16. Abstract

A flight test program was conducted to evaluate the characteristics of a spoiler roll control system on a light twin-engine airplane. The spoilers provided excellent roll control with no deadband or reduced sensitivity for small deflections. Roll power increased significantly with the flaps deployed. Cable stretch limited spoiler authority at high dynamic pressure. Data are presented on roll rates, sideslip, wheel deflections, and wheel forces.

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